2009

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From 2004 through 2007 runway incursions (RI), an FAA high priority safety item, have continuously increased (FAA, 2008). The FAA has sought mitigation proposals; here we suggest one such solution. Byrne, Kirlik and their students (2005, 2006, 2007) suggested one possible cause of RIs to be pilots making errors when given counterintuitive taxi instructions (i.e., turns away, as opposed to towards, their ultimate destination). Using this work as a foundation, we identified counterintuitive taxi geometries at Willard Airport (CMI), conducted an experiment with 14 certified flight instructors working at CMI in a simulation of landing and taxiing, and tested potential countermeasures. In addition to replicating Byrne and Kirlik's observations of systematic errors in turns violating experiential and geometrical expectations, we showed that our verbal guidance intervention aided all 7 pilots in correctly navigating the counterintuitive turn whereas only 1 of 7 within the control group did so.

Early in the morning of August 27, 2006 Comair flight 5191 crashed while attempting to take off from Blue Grass Airport in Lexington, Kentucky (NTSB, 2006). In a tragic turn of events, the airplane attempted to take off on runway 26 instead of runway 22. Runway 26 was too short for the aircraft to become airborne and it ran off the end of the runway killing 49 people. This accident illustrates the necessity for pilots to maintain geographical awareness of their assigned taxi instructions and their position on the airfield. These types of failures often result in runway incursions (RI) and, as illustrated in this example, can have tragic results.

Runway incursions are defined as "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft" (FAA, 2007, p. 43). RIs increased from 330 to 370 from FY2006 to FY2007. RIs in FY2008 numbered 1009. Likely though, this is due in part to the FAA's adoption of a new, more conservative, definition of runway incursion. (FAA, 2009). An investigation of causes of RIs in a review of 300 Aviation Safety Reporting System reports from FY2004 showed that pilots noted problems with expectations between where they perceived the hold short lines (the lines beyond which clearance is required to proceed) should be and where they anticipated they would hold in about one third of the incidents (FAA, 2005). Inappropriate actions based on these false expectations are known as expectancy violations and often result from the adverse influence of habit patterns. This finding suggests that aiding pilots in maintaining knowledge of position on the airfield may help reduce RIs.

In a study by Byrne, Kirlik and their students (2005, 2006, 2007) it was shown that pilot decision making methods changed across the spectrum from well planned out to guessing as available decision time was reduced in severe low visibility conditions (fog). Further, pilots were more likely to make errors when a counterintuitive taxi instruction (i.e., with turns away, as opposed to towards, their ultimate destination) was given. This characteristic behavior was modeled and validated through comparison with data from a NASA experiment of pilot navigation error in a simulation of Chicago O'Hare International Airport. In fact, every turn-related decision error in the NASA experiment could be explained by the model as owing to a counterintuitive relationship between the direction of the required turn and the turn that most closely corresponded to the direction of the destination gate. Thus, Byrne et al. identified one possible systematic cause of RIs.

Known human factors issues associated with automation are also relevant to the discussion of RIs; any mechanism created to aid pilots in preventing RIs must be designed accordingly. Automation can impair situational awareness (SA) due to changes in vigilance, complacency associated with monitoring, and changes in the quality of feedback provided to the human operator (Endsley & Kiris, 1995). An operator's level of trust in automation matters as well. Over-trust becomes an issue if an operator unduly trusts the system and accepts its counsel without fully understanding the entire situation. This complacency may lead to a difficulty in detecting automation errors, a loss in overall operator SA through failing to fully monitor the situation, and a potential degradation in skill (Wickens & Hollands, 2000). Under-trust, on the other hand, results in the pilot not choosing to use automation when it could increase safety. Despite these concerns, automation can provide novel solutions in addressing RIs when combined with an understanding of these human factors issues.

Based on these tenets, we explored the effectiveness of an automated intervention to prevent RIs due to counterintuitive taxi instructions. This intervention gave pilots progressive taxi instructions to and from their on-field destinations at counterintuitive taxi points and corrected them if they deviated from their prescribed route. We hypothesized that this intervention may help reduce the adverse impact of expectancy violations and habit patterns.

Method

We designed an experiment for experienced flight instructors with the goal of replicating the counterintuitive turn diagnosis of RI identified by Byrne, et al. (2005, 2006, 2007) as well as to test an intervention to prevent these types of errors. With help from a subject matter expert familiar with flight operations at Willard Airport (CMI), we located a point on the airport surface where pilot habit patterns were likely to be previously established and that these habits would be likely to transfer to a simulation. This afforded an opportunity to study expectancy violations due to a counterintuitive turn. To achieve this, an accurate re-creation of CMI airport was developed in an X-Plane® PC-based, flight simulator. To ensure generalizability to CMI, engineering drawings of all taxiway routes and markings were used. Instructor pilots with previous experience flying at CMI were chosen so that issues of unfamiliarity with CMI as well as control of the aircraft itself would not create confounding sources of error in the experimental results. That is, we did not want a pilot's inability to control the airplane to be a factor in the route they chose to taxi.

Our experiment investigated whether an intervention could prevent possible RIs at the point identified on the airfield when taxi instructions for counterintuitive turns were given. To create the setting for a counterintuitive taxi instruction, participants flew multiple approaches to a landing followed by taxiing to a known position (locally called the "orange corral") at CMI over two days. All but the last trial on the second day had the purpose of establishing a habit pattern so that when a counterintuitive taxi instruction was given on the last trial it would be unfamiliar. The pilots were told that they were evaluating the simulator itself and were not aware of the purpose of the experiment until the end of their participation. This was required because knowledge of the experimenters' intent could affect the participants' performance of the task.

On the first day of the experiment all participants were asked to land on runway 32R then taxi to the orange corral on A5, A, and A2 (Figure 1) via prerecorded ATC instructions. This scenario was repeated eight times. On the second day all participants had the same scenario as the first day for the first seven trials. On the eighth, and final, trial of the second day the taxi instruction was altered to taxi to the orange corral via A5, A6, A, A2 (Figure 2). The only difference between the two groups of pilot participants was that a simulation of our intervention was active for the experimental group, but not for the control group. This intervention cued the A6 turn (counterintuitive turn) once the turn off of 32R was completed and gave course corrections in the event the prescribed taxi route was deviated from. The intervention cue for A6 consisted of the statement, "Now approaching alpha six, turn right to zero niner two, onto alpha six."

The researchers took written notes during each session on participant taxi routes and verbalizations. Participants were encouraged to treat the simulated flights as if they were actual flights and they were specifically requested to make read-back calls to ATC as if they were actually using the radio. To better recreate normal taxi conditions, they were also instructed to taxi at speeds they typically used at CMI.

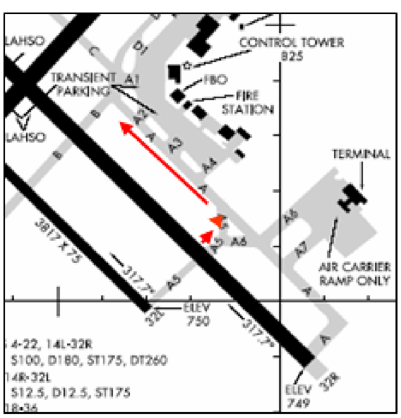

Figure 1. The nominal (experientially & spatially intuitive) taxi route used during all but the final trial of the second day.

Figure 2. The counterintuitive taxi route used during the final trial of the second day.

In addition to the intervention just described, we tested a different intervention with one additional participant. This intervention was simply to add the phrase to "I say again" to the last trial's taxi instructions in the attempt to raise the saliency of the counterintuitive turn. For this participant, the procedure was identical to the control group except the taxi instruction was: "Turn right on A5 taxi to Orange Corral via A5, A6, I say again A6, A, A2" in the final trial. The intention was to test if repetition of the counterintuitive turn in the instruction would raise awareness of its counterintuitive nature.

Results

Each participant's performance was assessed based on his or her taxi instruction read-back and turn to A5 or A6 during the final trial on the second day. Four of the 7 participants in the control group read back the taxi instruction correctly; whereas only 1 in the intervention group did. However, only 1 person in the control group followed the correct taxi route (14% success rate). Despite taking the correct route, the observer noted participant hesitation at the turn's decision point. Many other control group participants also demonstrated hesitation independent of whether their taxi instruction read-back was correct or not.

In the intervention group, all 7 of the participants made the correct turn onto A6. Hesitation and confusion were noted (e.g., some participants had an inquisitive voice inflection, questioning the taxi instruction's inclusion of "A6"). The difference in the two groups' taxi performance was statistically significant ($\chi^2_{Yates} = 7.29$, $p < 0.01$). Finally, for the participant given the taxi "I say again" intervention, the participant made both the correct read-back and correct taxi route. During the post-experiment debriefing the participant stated that hearing A6 stuck out from the routine taxi instructions, but hearing "I say again, A6" made it very salient.

Discussion

This experiment sought to determine if some taxi errors result from expectation failures and if so, test a way of mitigating this problem. Pilot expectations and habits are difficult to overcome in atypical situations; this was demonstrated in that only 1 participant in the control group took the correct route while the 6 remaining participants took the habitual route. This provides converging evidence with Byrne, et. al. (2005, 2006, 2007) that counterintuitive turns are a possible systematic cause of RI errors. In contrast to the control group, all 7 of the participants in the experimental group made the correct turn to A6. These results suggest that our intervention contributed to the experimental group's success in taking the correct taxi route over that of their habit patterns.

Our anecdotal test of the "I say again" intervention produced quite interesting results. This pilot had distinctly more confidence in the taxi instructions than those in the experimental or control groups. We attribute this to the repetition of the instruction regarding the counterintuitive turn. This repetition provided indication of an awareness of issuing a non-conventional taxi route and also provided confirmation that the taxi instruction was not in error. This type of modification could be accomplished by training each airport's air traffic to identify non-standard/counterintuitive taxi routes and repeating those sections while issuing taxi instructions.

Conclusion

Runway incursion prevention is crucial to aviation safety. Our intervention was designed to prevent one possible cause of taxi navigation error that has been found, both in our study, and previously by Byrne, et. al. (2005, 2006, 2007). These results provide converging evidence that a systematic and addressable source of taxi error lies in habit patterns and counterintuitive taxi routes. We have demonstrated that interventions that alert and direct pilots at counterintuitive turn points can reduce the prevalence of these errors. With additional research we believe that these types of interventions could be implemented with existing technology in aircraft and on the airfield, and thus could be an effective and timely solution to RI prevention at all sizes of airports. In summary, a possible systematic cause of human error has been identified and an intervention has been proposed and empirically demonstrated to eliminate or reduce these errors.

Acknowledgements

This research was originally submitted to the FAA's Design Competition for Universities on April 17th, 2008 as a part of the Human Factors Proseminar course at the University of Illinois at Urbana-Champaign under the direction of Professor Alex Kirlik. We appreciate the assistance of Mr. Don Talleur, Prof. Jason McCarley, Prof.

Dan Morrow, and Mr. Jonathan Sivier of the University of Illinois. We also thank Dr. David Foyle of NASA and Prof. Steven Landry of Purdue who were also integral in shaping our research. The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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